EFFECTS OF TRAINING AGAINST ELASTIC RESISTANCE ON JAB PUNCH PERFORMANCE IN ELITE JUNIOR ATHLETES

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Abstract:

Ability to perform rapid open-kinetic chain movements (e.g. kicking, throwing, hitting, or punching) is an important prerequisite for success in various sports. The aims of the present study were (1) to investigate the effect of elastic resistance training (ERT) on the performance of jab punch, (2) to explore the associated changes in movement kinematic and kinetic patterns, and (3) to assess possible differences among competitors of different specializations. The national level junior competitors in kick boxing, savate, and boxing practiced jab punch against elastic resistance for 15 minutes per day, 3 times a week for 6 weeks, while the control group participated only in their regular training (N=10+10+10+10; age 17.2±1.0 years; M±SD). The results revealed a marked increase in the maximum jab punch velocity in all experimental groups (6-11%; all $p<.01$), but not in the control group ($p>.05$). This finding was associated with an increase in both the maximum velocity and displacement of the ipsilateral elbow, shoulder, and, particularly, hip joint, while no change in the movement time was observed. The ERT-associated increase was also revealed in the agonist (7-11%, all $p<.01$), but not antagonist muscle strength. Therefore, we conclude that addition of a relatively small amount of ERT could be recommended for the purpose of improving punching performance and, possibly, other rapid limb movement even in top-level junior athletes. The observed performance improvement could be partly based on increased motion amplitudes particularly regarding the pelvis movement, as well as on increased strength of agonist muscles.

Key words: *open kinetic chain, movement, velocity, displacement, strength, martial arts*

Introduction

Standard strength training programs for athletes typically combine closed- and open-kinetic chain exercises to improve the core upper- and lower-body strength, sport-specific strength, and performance, as well as for injury prevention (Prokopy, et al., 2008). Closed-kinetic chain exercises require fixing the distal segment or providing it with a considerable resistance (Steindler, 1955), such as the hands pushing against the ground during a push-up. Open-kinetic chain exercises allow the end- point to move freely either with or without external resistance, such as when performing punches, throws or kicks, or exercising with free weights (West, Cunningham, Crewther, Cook, & Kilduff, 2013). Since the kinematic patterns typical for rapid movements of open-kinetic chains are known to maximize the end-point velocity, such movements were favored by coaches for the purpose of upper-body training (Dillman, Murray, & Hintermeister, 1994). Nevertheless, other studies recommended the closed-kinetic chain upper-body training led for improving throwing performance (Prokopy, et al., 2008).

Proximal-to-distal sequences (Cabral, João, Amado, & Veloso, 2010) of individual body segments was observed in throwing, striking, or kicking movements performed in variety of sports, often with the aim to maximize velocity of the end- point (Marshal & Elliott, 2000). For example, the peak linear and angular velocities were found to progress from the trunk to the wrist in a squash forehand stroke and the segmental velocities increased progressively throughout the kinematic chain (Woo & Chapman, 1994). Baseball players accelerate the elbow and wrist joint rotations by utilizing the velocity-dependent torque that is originally produced by the proximal trunk and shoulder joint torques (Hirashima, Yamane, Nakamura, & Ohtsuki, 2008), while the peak pelvic angular velocity during the volleyball spike performance precedes the shoulder external rotation and both contribute to a higher ball speed (Dunbar, Chmielewski, Tillman, Zheng, & Conrad, 2012).

This all lead to a conclusion that to understand the mechanisms in performance improvement of the movements such as throwing, striking, or kicking, the role of all open-kinetic chain body segments need to be explored.

Punching movements, typical for many combat sports and martial arts, represent a typical example of the open-kinetic chain movements where the main task is to maximize hand velocity as the main performance variable. For example, the straight jab punch, thrown by the lead hand in boxing (also known as reverse punch in karate) is a fundamental, score-making, and powerful skill (Cheraghi, Alinejad, Arshi, & Shirzad, 2014). The magnitude of force exerted at the point of impact is governed by a number of factors, among which are: force generated by the legs (Filimonov, Koptsev, Husyanov, & Nazarov, 1985), degree of body rotation, and the distance over which the punch is thrown (Hickey, 1980). The trajectory of the hand in the anterior-posterior direction indicates a higher velocity in a throwing phase than that portrayed in a returning phase. Hip anterior displacement represents a weight shift toward intended direction of the punch. Nevertheless, the role of particular segments and the involved muscle groups in punching still remains unresolved, which inevitably constrains development of training methods aimed at improving performance. One of the reasons for that is that the punching techniques could considerably differ both within and across various martial arts and combat sports, such as boxing, karate, taekwondo, or kickboxing (Marshal & Elliot, 2000; Cohran, 2003; Cabral, et al., 2010, Loturco, Artioli, Kobal, Gil, & Franch, 2014).

Regarding the training interventions aimed at improving performance of rapid and explosive open-kinetic chain movements, the transferability of strength gains achieved from general resistance training methods to sport-specific performance still remains unclear (Hetzler, et al., 1997; Newton, Kraemer, & Hakkinen, 1999). It has been often recommended that a higher training transfer to the actual performance could be achieved from exercises based on the specific movements performed in competition (Stone, Plisk, & Collins, 2002; Kanehisa & Miyashita, 1983). The specific strength training programs often used ballistic movements with medicine balls (Szymanski, Szymanski, Bradford, Schade, & Pascoe, 2007; Ignjatovic, Markovic, & Radovanovic, 2012; van den Tilaar & Marques, 2009, 2013), dumbbells and barbells (West, et al., 2013; Marques, van den Tilaar, Vescovi, & Gonzalez-Badillo, 2007), as well as the elastic resistance training (ERT) methods (Davies, 2003; Treiber, Lott, Duncan, Slavens, & Davis, 1998; Dinn, & Behm, 2007; Jakubiak, & Saunders, 2008). The exercises based on ERT also found application in the recovery and rehabilitation of athletes (Ellenbecker, Pluim, Vivier, & Sniteman, 2009). The use of ERT methods for improving kicking performance was already recommended (Davies, 2003). However, there were few studies aimed at examining the effects of ERT on other rapid open-kinetic chain movements. For example, effectiveness of ERT in improvement of serving speed in elite tennis players was demonstrated (Treiber, et al., 1998), while a study conducted on taekwondo competitors revealed similar results regarding the improvement in the kick velocity (Jakubiak, et al., 2008). However, the mechanisms involved in the improvement of open-kinetic chain performance associated with ERT remain largely unknown. Among the candidates could be both the training-associated changes in muscle strength and/or movement kinematic and kinetic patterns. Significant correlations have been found between muscle torque and punch force in boxers that emphasizes a possible role of muscle strength in movement performance (Karpiłowski, Nosarzewski, Staniak, & Trzaskoma, 2001). However, the possible changes in the movement kinematic patterns remain largely underexplored.

To address the discussed problems, the first aim of our study was to explore the effectiveness of ERT on jab punching in young individuals with already a high level of the movement performance. Specifically, we introduced a moderate amount of ERT to elite junior athletes in addition to their regular training. Our second aim was to explore the changes in movement kinematic pattern that could have contributed to the expected improvement in movement performance. Specifically, we explored the training-associated changes in both the velocity and displacement of selected body segments of the tested open-kinetic chain. Our third aim was to explore the possible differences in both the effectiveness of the ERT training and the changes in kinematic patterns among the athletes of different specialization. Findings of the present study could contribute not only to refinement of training procedures aimed at improving jab punching and other rapid open-kinetic chain movements performance, but also to advancing our understanding of the mechanisms involved in the performance improvement.

Methods

Experimental approach to the problem

To assess the effects of moderate amount of elastic resistance training (ERT) on both the improvement in punching performance and the involved mechanisms, three experimental and one control group of junior elite athletes of partly different combat sport specializations were tested both prior to and after 6 weeks of ERT. In addition to the peak velocity of hand as the main performance variable, the associated changes in kinematic patterns of other elements of the tested open-kinetic chain was assessed by peak velocities and displacements of the elbow, shoulder and hip joint. To assess a possible role of muscle strength in the tested movement performance, the training-associated changes in strength of elbow flexors and extensors were also evaluated.

Subjects

The participants (N=40) were experienced junior male athletes that were active in the following combat sports: kick boxing (KB; n=14), savate boxing (SB; n=13) and boxing (BO; n=13). They were assigned to three experimental groups according to their specialization (10 subjects each), while the control group (n=10) consisted of randomly selected remaining 3 KB, 4 SB and 3 BO athletes. All participants were the national level competitors, as well as members of the national junior teams. Their age (M±SD) was 17.2±1.0 years, body height: 1.79±0.07 m, and body mass: 72.8±7.5 kg. No significant differences in either the body size or age were observed among the groups (all p>.1). Their training experience was between 5.0 and 9.5 years, and at the time of the study all of them were involved in their regular training protocols implemented between 6.0 and 10.5 hours per week. The protocols did not involve any kind of resistance training.

All participants were healthy and in good physical condition. None reported injuries or illnesses that could compromise the tested performance, neither they had had previous experience with ERT. The study was approved by the local IRB and written assents were obtained from all participants as well as from their parents prior to any testing.

Experimental protocol

The testing was conducted prior to (i.e. the pretest) and three days after a 6-week training period (posttest). Both the pretest and posttest consisted of a single session aimed to test the maximal velocity and displacement of tracked joints, as well as to assess the elbow extensor and flexor muscles' strength. The pretest was preceded by anthropometric measurements where body mass and height were assessed by a digital scale and a standard kinanthropometer, respectively.

Jab punch testing

Following a standard stretching and warm-up procedure consisting of five minutes cycling and 10 minutes of callisthenics and dynamic stretching, the subjects were instructed to perform jab punches to boxing punch mitts, all in the same stance (the non-dominant leg leading). The target was adjusted for individual boxers to their preferred height and distance to address the task constraint of delivering their best dominant hand jab punch to a level of the imagined opponent head. Subjects were instructed to throw punch as fast as they could.

Four tightly secured reflecting markers were placed at the subjects' body to record joint motion of specific joints (see Figure 1). Specifically, they were placed over the bony landmarks of their dominant side wrist (*styloid process of the radius*), elbow (*lateral epicondyle of humerus*), shoulder (*acromion process*), and hip (*anterior superior iliac spines*). A three-camera motion capture system (ProReflex infrared, Qualisys 3D), sampling at a frame rate of 240 Hz, was applied to capture velocity and range of motion of wrist, elbow, shoulder, and hip joints during the jab punch performance. The capture system was positioned at the lateral body side to avoid covering the markers by other body segments over the course of testing. The standard commercial software (Qualisys Track Manager; QTM) for 3D motion capture was used to record 3D coordinates of the markers. The between-day reliability of kinematic variables obtained using a similar approach proved to be high (Brian, Manal, & Davis, 2010).

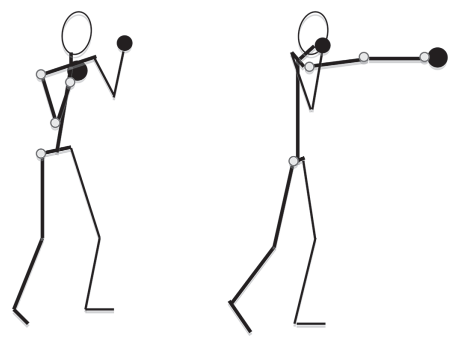

Figure 1. Illustration of the initial (left hand side) and final body posture (right hand side) together with the position of the attached reflected markers (empty circles)

Muscle strength test

To assess a possible training-associated increase in the strength of muscles acting against the applied resistance and contrast it with their antagonists, we selected the elbow extensor and flexor muscle and tested their maximum isometric force (Abernethy, Wilson, & Logan, 1995; Jaric, 2002). The apparent candidates for this selection were also the shoulder, hip, and knee extensors and flexors, but we believed that elbow muscles, being the weakest, could be most exposed to the applied resistive force. The test was conducted on the elbow flexor and extensor muscles by means of a standard Kin-Com isokinetic dynamometer (Chatex Corp., Chattanooga, TN) set to static condition. The subject was fixed to the dynamometer by wide tight straps according to manufacturer recommendations. The axis of the dynamometer was aligned with the elbow joint axes set to 120° (180° being full extension). The subjects were instructed *to rapidly exert the maximum force* against the band attached to the dominant forearm and to retain it for 3-4 s (Wilson & Murphy, 1996). The extensor and flexor muscles were tested in random sequence. On-line feedback regarding the current force level was shown at a computer monitor positioned in front of the subject and verbal encouragement was provided. Three consecutive trials were performed with 2-minute rests and the trial with the highest force was taken for further analysis as the measure of strength.

Training

The same training intervention was added to regular training routine of all subjects of the three experimental groups. The program of ERT was applied three times a week for six weeks. Specifically, the subjects performed six sets of ten repetitions of jab punch each with the instruction to reach the target (i.e. boxing punch mitts) as fast as possible.

The rest intervals between two consecutive trials were 10 s and subjects rested between 45 and 60 s between the sets. Each session was conducted at the end of their regular training session and lasted approximately 15 minutes.

The applied elastic resistance was same for all subjects. It originated from rubber bands (resting length 1.5 m, coefficient of elasticity 133 N/m) with one end externally fixed behind the subject, while the subject held the other end by his punching hand. Initially, the bands were pre-stretched about 15cm at the starting hand position. Since the hand displacement was on average about 90cm, the resisting elastic force increased from approximately 20N to 140N (i.e. between the starting and final hand position). The resistive force was progressively increased by adding 20cm of a pre-stretch per week which resulted in about 26.5N increase in resistance (see Jakubiak, et al. 2008, for similar approach). Therefore, resistive force during the last week of training ranged approximately between 150N and 270N.

Data analyses

The signals from the cameras were sampled at a rate of 240 per second and filtered by a second-order Butterworth recursive low pass filter (10Hz cut-off frequency). A custom-designed Lab VIEW (National Instruments, Version 8.2) program was used to calculate the scalar values of 3D position and velocity of each marker. The analyzed time interval began at the first visible initiation of the wrist movement (i.e. when it reached 3% of its maximum velocity) and lasted until the hand's impact with the boxing punch mitts set as a target. It allowed for the calculation of peak velocity (V_{peak}) and displacement (D_{isp}) of the reflecting markers placed at the hip, shoulder, elbow and wrist joints, as well as for the assessment of movement performance time. The standard test provided information on strength of the elbow extensor (F_{ext}) and flexor (F_{flx}) muscles.

Statistical analysis

Descriptive statistics were calculated for all dependent variables as means and SD. Thereafter, a series of mixed model 2-way ANOVAs with the main effects of *time* (2 levels) and *group* (4 levels) were conducted on individual variables with Boferroni *post-hoc* test for planned contrasts. The Cohen's effect size (ES) was also calculated and the values of 0.2, 0.5, and 0.8 were considered as small, moderate, and large effects, respectively. Alpha was set to 0.05.

Results

Subjects of three experimental groups had 100% attendance of ERT, as well as a 100% compliance with the prescribed number of ERT sets and repetitions. Training with elastic resistance did not contribute to visible distortion of their movement technique, as observed by experienced boxing coaches.

Figure 2 shows the kinematic variables observed in the pretest and posttest and averaged across the subjects of all 4 groups. The upper panel depicts the values of V_{peak}. Arguably, the most important individual variable is V_{peak} of the wrist that represents the main task variable. The applied 2-way ANOVA revealed a significant time-group interaction ($F=21$, $p<.01$; $ES=.64$), as well as the significant main effect of time ($F=213$, $p<.01$; $ES=0.86$), but not of the group ($F=2.3$, $p>.05$; $ES=.16$). Similar findings were observed for V_{peak} in the remaining 3 joints. Namely, V_{peak} of the elbow also revealed a significant time-group interaction ($F=11.5$, $p<.01$; $ES=.49$), a significant main effect of time ($F=99$, $p<.01$; $ES=.73$), but not of the group ($F=1.4$, $p>.05$; $ES=.11$). V_{peak} of the shoulder also revealed a significant time-group interaction ($F=17$, $p<.01$; $ES=.59$), the significant main effect of time ($F=167$, $p<.01$; $ES=.82$), but not of the group ($F=2.1$, $p>.05$; $ES=.15$). Finally, V_{peak} of the hip revealed a significant time-group interaction ($F=4.6$, $p<.01$; $ES=.28$), the significant main effect of time ($F=41$, $p<.01$; $ES=.53$), but not of the group ($F=2.0$, $p>.05$; $ES=.14$). The general finding across the tested variables is that Bonferroni *post-hoc* test showed significant increase in V_{peak} between the pre- and posttest in all four joints of the three experimental groups, but not in the control group.

Regarding the observed changes in the displacement, D_{isp} of the wrist showed a significant time-group interaction ($F=6.0$, $p<.01$; $ES=.33$), the significant main effect of time ($F=61$, $p<.01$; $ES=.63$), but not of the group ($F=.3$, $p>.05$; $ES=.02$). D_{isp} of the elbow revealed a significant time-group interaction ($F=7.0$, $p<.01$; $ES=.37$), the significant main effect of time ($F=67$, $p<.01$; $ES=.65$), but not of the group ($F=.3$, $p>.05$; $ES=.02$). D_{isp} of the shoulder also revealed a significant time-group interaction

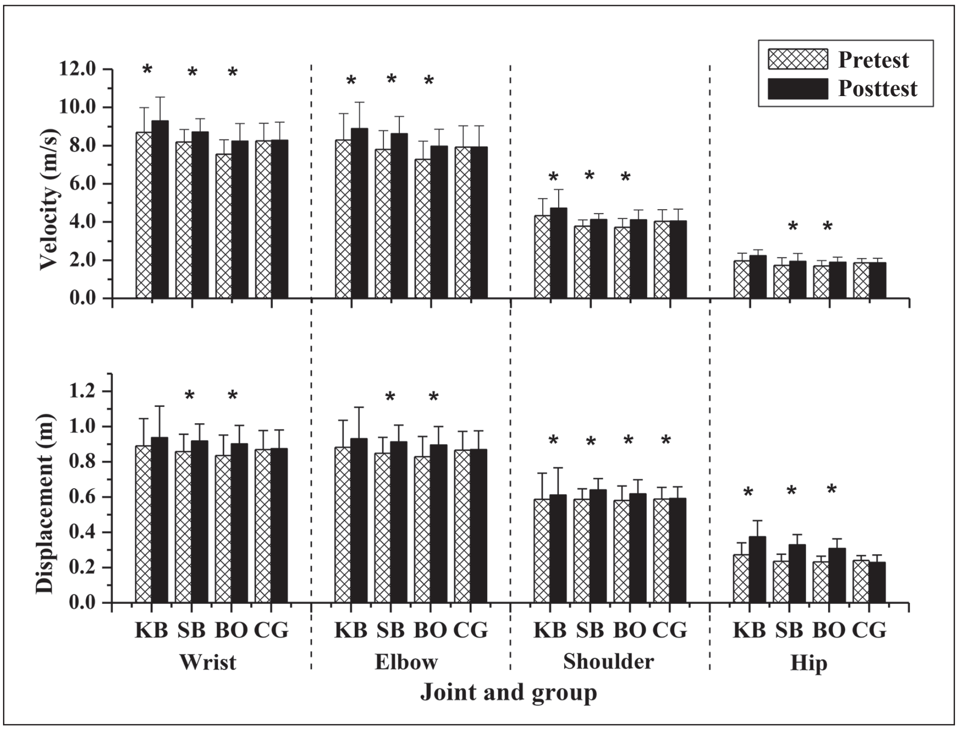

*Figure 2. Peak velocity (top panel) and displacement (bottom panel) observed in 4 joints in the pre- and posttest in four groups (data averaged across the subjects with SD error bars; * p<.05, paired t-test).*

(F=7.6, p<.01; ES=.39), the significant main effect of time (F=59, p<.01; ES=.62), but not of the group (F=.1, p>.05; ES=.01). Only D_{isp} of the hip revealed both the significant time-group interaction (F=25, p<.01; ES=.67), and the main effects of both the time (F=154, p<.01; ES=.81) and group (F=4.8, p<.01; ES=.28). Collectively, similar to V_{peak}, D_{isp} showed a significant increase in V_{peak} between the pre- and posttest in all four joints of all experimental groups, but not in the control group. The only exception was the shoulder D_{isp} obtained from KB group that remained somewhat below the Bonferroni corrected p=.0125.

A potentially important finding could originate from the comparisons in the changes observed across the joints (see Figure 2 for the data). However, since the results are obtained by 2-way ANOVAs originated from individual variables and joints, they do not allow for such comparisons. Nevertheless, note that the qualitative analysis suggests that the training-associated relative increase in D_{isp} is markedly more pronounced in the hip than in other joints. That is reflected both in the highest ES of the time-group interaction and in the relative increase in D_{isp} of about 40% in all the three experimental (but not in the control) groups. The increase in the other three joints is typically less than 10%.

Another finding of potential importance is the effect of ERT on movement time. Specifically, the data revealed movement time observed in the pre- and posttest was, respectively, 197±26 and 192±29ms in KB, 206±32 and 215±23ms in SB, 214±24 and 217±38ms in BO, and 200±16 and 202±17ms in CG. Of importance here is that none of the differences was significant (all p>.1; one-group *t*-test).

Finally, Figure 3 shows the data obtained from the elbow extensor and flexor muscle expected to assess the training-associated increase in muscle strength. The elbow extensor revealed the significant main effect of time (F=150, p<.01; ES=.81), but not of group (F=2.4, p>.05; ES=.17), and a significant time-group interaction (F=13, p<.01; ES=.51). Strength significantly increased in all the experimental, but not in the control group. Regarding the elbow flexor, the results revealed neither the main effects of time (F=1.9, p<.01; ES=.05) or group (F=.8, p>.05; ES=.07), nor their interaction (F=.7, p>.05; ES=.06).

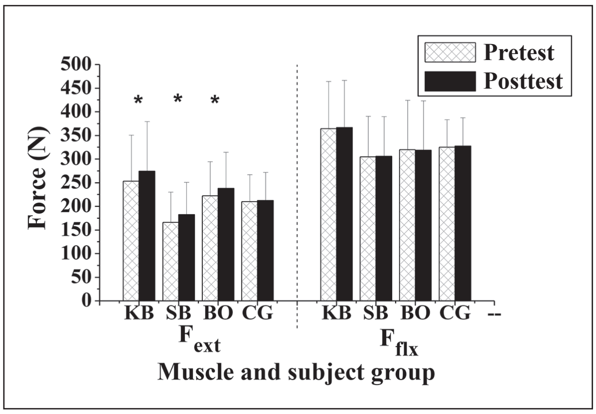

*Figure 3. Strength of elbow extensors and flexors observed in the pre- and posttest in four groups (data averaged across the subjects with SD error bars; * p<.05, paired t-test).*

Discussion and conclusions

Within the present study we evaluated the effectiveness of ERT in performance improvement of rapid open-kinetic chain movements. Specifically, we tested the jab punch of elite junior athletes competing in different combat sports. Regarding the first aim of the study, we found that a relatively small amount of ERT could result in a significant increase in hand peak velocity in athletes of different specializations. Regarding the second aim, among the mechanisms involved in the performance increase could be a markedly increased displacement of individual joints, particularly pronounced in the hip, as well as an increase in the agonist but not antagonist muscle strength. However, despite the increased displacement, movement time remained unchanged. Regarding our third aim, we did not find any differences in any of the ERT-associated changes.

The main finding of the study is an ERT-associated increase in movement performance as assessed by the wrist peak velocity (V_{peak}; see Figure 2). Of particular importance could be that the finding was observed in individuals who were already both highly selected and trained for that particular movement performance. Moreover, the effect was pronounced despite subjecting the participants to only about 45 minutes of ERT training per week, that on average represented about 10% of their total training time. Note also that although the movement distance (as assessed by D_{isp} of the wrist) increased, the total movement time remained approximately unchanged. This brings an apparent advantage to various combat sports and martial arts since the athlete is able to reach to his/her opponent from a more remote position over the same movement time (Dunbar, et al., 2012; Hirashima, et al., 2008; Jakubiak & Saunders, 2008). Therefore, one could conclude that ERT may be highly effective in increasing performance of rapid arm movements such as the tested jab punch and, perhaps, other open-kinetic chain movements (Davies, 2003; Jakubiak & Saunders, 2008).

Of particular importance for the main finding discussed in the previous paragraph could be the mechanisms involved in the observed performance improvement. The kinematic data suggest that an increase in the wrist V_{peak} was associated with an increase in both V_{peak} and displacement (D_{isp}) in all joints (Dunbar, et al., 2012). However, note also that the most prominent increase in D_{isp} was observed in the hip joint of ipsilateral leg. For example, the relative increase of D_{isp} of the hip in all the three experimental groups was close to 40%, while the same increase in other three joints was typically below 10% (see Figure 2). As a result, one could conclude that the observed increase in D_{isp} and, consequently, V_{peak} could largely originate from a more pronounced pelvis motion (Cabral, et al., 2010; Cheraghi, et al., 2014; Szymanski, et al., 2007). Another mechanism responsible for the discussed performance improvement could be increased muscle strength. Although we selected only one muscle group, note that while the agonist (i.e. elbow extensors) revealed a marked strength increase of 7-10%, the antagonist strength increase was virtually zero. This result is in line with numerous studies of the effects of external load on the agonist-antagonist activity in single-joint movements (Dinn, et al., 2007; Ignjatovic, et al., 2012). Specifically, it is known for decades that while an increased inertial load (e.g. added weight) requires increased activity of both the agonist and antagonist (i.e. to propel and, thereafter, to terminate the movement), an increase in elastic resisting force (such as the applied ERT) requires only increased agonist activity, since the applied resistance acts as an antagonist *per se* (Hoffman & Strick, 1993). Nevertheless, the relative contribution of two discussed mechanisms to the observed performance enhancement (i.e. the altered movement kinematic pattern and increased muscle strength) certainly deserve attention of future studies.

The effects of applied ERT appeared to be similar across the three experimental groups. In addition to a possible lack of statistical power to detect possible differences, one could also speculate that the lack of the discussed differences originates from similarities in the tested groups. Namely, all the three experimental groups were both selected and trained in a relatively similar way. However, while one could presume that the jab punch technique was also similar across the groups, note also that moderate differences in the performance (i.e. V_{peak} of the wrist) were observed among them.

Several limitations of the present study, as well as the directions for future research need to be recognized. First, of considerable importance could be that the observed effectiveness of ERT was obtained from only one type of open-kinetic chain movement. Therefore, the applied training program should be evaluated on other rapid open-kinetic chain movements, such as on throwing or kicking. Second, future studies should conduct a more elaborate exploration of the mechanisms involved in the observed performance enhancement. For example, the possible changes in movement patterns associated with ERT could deserve attention, and the same applies both to strength and to the rate of force development of the muscle groups involved (Mirkov, Nedeljkovic, Milanovic, & Jaric, 2004). Regarding punching *per se*, one could be also interested in effectiveness of the tested punch regarding its impact speed, effective mass, and, consequently, the associated momentum. Third, although we detected significant effects of the applied training program on both the kinematic and kinetic variables, the groups were perhaps too small to identify the differences among them. Nevertheless, we ran a *post-hoc* statistical power analysis regarding the differences in percent increase in performance and other variables observed across the three experimental groups and typically obtained sample sizes of above 30 participants per group needed to detect significant differences among them. Finally, both the optimum magnitude of the applied load and the rate of its increase over the course of the applied training program certainly deserve attention of future studies.

To conclude, the results revealed that a relatively small amount of ERT added to a regular training program could be effective in the enhancement of jab punch performance even in highly trained athletes. The enhancement was observed in an increase of both velocity and displacement of the hand and it could be considerably based on the altered movement pattern (particularly regarding an increased involvement of the pelvic movement), as well as on the increased strength of agonist muscles. No differences among the athletes already specialized in KB, SB, and BO were recorded regarding the observed outcomes. Future studies could explore to which extent the obtained finding could be extended to other important open-kinetic chain movements (e.g. throwing, kicking, etc.), as well as more elaborately explore the role of both load magnitude and alteration of kinematic and kinetic patterns associated with the applied ERT training. Regarding the punching task *per se*, both the velocity of the hand at the instant of real impact and the effective mass could deserve attention of future studies.

High performance of rapid open-kinetic chain movements, such as kicking, throwing, hitting, or punching, is an important prerequisite for success in various sports. We found that a moderate amount of jab punching practice against elastic resistance, added to the standard training routines, could markedly improve punching performance (i.e. hand peak velocity) in young elite competitors in various combat sports. That improvement is probably based mainly on larger displacements without any penalty in terms of prolonged movement time, although the increased muscle strength of the agonist muscles could also play a role in it. Therefore, an addition of a relatively small amount of training against elastic loads could be recommended for the purposes of increasing performance of the rapid limb movement even in athletes of a relatively high level of proficiency.

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